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# Psychophysical Localization of the Human Visual Streak

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## ABSTRACT

**In a topographical study of the human retina, Curcio and Allen documented the presence of the human visual streak, which they described as a prominent nasotemporal asymmetry in ganglion cell density. This asymmetry could also be expected to be measurable in any visual function limited by ganglion cell density. By using an interferometer we sought to test the hypothesis of Thibos et al. that peripheral resolution acuity is limited by the spacing of ganglion cells and should therefore reflect the anatomical asymmetry of the visual streak, once the attenuating effects of the eye's optics have been removed. This proved to be the case and differences predicted by a ganglion cell density of 2:1 were easily measurable. This study has potential clinical implications for the detection of disease or abnormalities of the visual system that cause death or dysfunction of retinal ganglion cells.**

**Key Words: visual streak, peripheral visual acuity, ganglion cell density**

Clinical diagnosis of those retinal and optic nerve diseases characterized by ganglion cell death, such as glaucoma, optic neuritis, and age-related maculopathies, would be aided by a noninvasive, psychophysical measurement of retinal ganglion cell density.[1] Recent experiments have suggested that peripheral visual acuity could serve in this capacity if certain requirements are met. First, optical limitations due to peripheral refractive error and chromatic aberrations must be avoided. This goal is easily achieved by using one of the commercially available monochromatic interferometric visual stimulators.[2, 3] Second, the psychophysical task of the patient must be one which can be related directly to the coarseness of the retinal mosaic of ganglion cells. In the peripheral retina, cones greatly outnumber the ganglion cell population,[4] which means that spatial acuity should be limited not by cone spacing (as it is in the fovea) but by the relatively coarse spacing of the ganglion cells.[5–7]

Direct proof that peripheral acuity is sampling-limited comes from observations of "aliasing" of grating stimuli which are too fine to be resolved.[8–10] The term aliasing refers to the misperception of a stimulus of high spatial frequency as a pattern of lower spatial frequency, and often of a different orientation as well. Aliasing could be caused by undersampling of the retinal image at any level of the visual system, including the photoreceptors. Therefore, if we take visual acuity to mean the lowest stimulus frequency which evokes aliasing, then acuity will be a measure of the sampling density of the coarsest array in the visual pathway. Quantitative comparison of acuity with the spacing of retinal neurons points to the ganglion cells as the limiting factor for eccentricities beyond about 15°.[7] Thus the available evidence indicates that measuring peripheral resolution acuity in the absence of optical limitations provides a noninvasive assessment of ganglion cell density in the living human eye.

If the foregoing is correct, then psychophysical measurements of visual acuity ought to confirm the prominent anatomical features of the mosaic of retinal ganglion cells. For example, mammalian ganglion cell density distribution maps reveal that a large number of mammals possess retinas in which a "visual streak" is superimposed on a centrally or temporally localized visual pole or fovea.[11] There have been several topographical studies specifically examining the distribution of ganglion cells across the human retina.[12, 13] These studies reveal the presence of a weak visual streak which has been described by Curcio and Allen[13] as an area of relatively higher ganglion cell density along the nasal horizontal meridian. This study reported the gan-

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glion cell isodensity contours to be egg-shaped and displaced nasally, meaning the nasal retina has more cells than any other meridian at corresponding eccentricities. Moving peripherally, this elongation was more marked with the nasal/temporal density ratios at corresponding eccentricities on the nasal and temporal horizontal meridian ranging from 1.4:1 at the optic disk to 4.2:1 at the edge of the temporal retina. Also it was reported that a superior-inferior asymmetry was present; the superior retina had on average 60% more ganglion cells than corresponding eccentricities in the inferior retina. This superior/inferior asymmetry ratio ranged from 1 to 3.75 but it was much more variable among individuals.

An early classical study by Wertheim[14] sought to measure peripheral acuity using grids which were moved toward the eye at different eccentricities until "recognised." His data indicated higher acuity in nasal retina than temporal retina. Rovamo et al.[15] measured grating resolutions at various locations in the visual field using a cathode ray screen and four different grating orientations. Their results did not indicate any particular asymmetry between nasal and horizontal retina; however, the effects of the eye's optics, namely peripheral astigmatism and transverse chromatic aberration, were not eliminated. Walsh[16] measured peripheral acuity throughout the retina with a white light interferometer and found nasal acuity to be superior to temporal acuity. Unfortunately, this device is known to be affected by transverse chromatic aberration,[3] which complicated interpretation of those results.[8]

None of the previous investigators mapped the location of the blind spot—a necessary exercise for comparing the psychophysical data with predictions derived from anatomical studies because anatomical counts usually localize with respect to the fovea (eccentricity) and optic disk (meridian). For the present study we used a monochromatic interferometer to overcome the limitations of previous studies and used the aliasing criterion for resolution to ensure that acuity was sampling-limited.

## METHODS

We used a modified Lotmar Visometer (Haag-Streit, Berne) to minimize the defocusing effects of the eye's optics.[17] This instrument, which is essentially similar in principle to previously described monochromatic interferometers,[18, 19] is a Maxwellian-view visual stimulator which uses a pair of crossed diffraction gratings illuminated by collimated light from a tungsten source to produce two coherent point sources. These point sources are then imaged near the nodal point of the eye to produce sinusoidal interference fringes directly on the retina. To avoid the effects of the eye's chromatic aberration,[20] the light source was filtered by a 550-nm interference filter. The angular period of the fringes subtended at the nodal point of the eye (and hence the spatial frequency) is given by the ratio of the wavelength of the light divided by the spacing of the point sources, and is controlled by varying the angle between the two diffraction gratings. The resulting stimulus was a patch of sinusoidal grating of high fixed retinal contrast with a mean luminance of 200 Td (photopic) and a diameter of 2.5°. Spatial frequency was continuously adjustable by the subject over the range 0 to 75 cycles per degree (cpd). Before the experiment began, the size and position of the physiological blind spot was plotted for each subject using the Bjerrum screen. The line joining the center of the blind spot and the fovea was taken as the anatomical horizontal for the experiment.

The visometer was mounted on a gimbal so that the stimulus could be positioned at selected locations and orientations in the visual field. The 0° meridian of the gimbal was tilted to match the previously determined anatomical horizontal (356°). The subject's head was held still and erect by means of a bite-bar. Eyes were in the primary position with the eye not in use patched. Fixation was maintained using a 2-mm red light-emitting diode 4 m in front.

Two experienced observers (RSA and MOW) took part in the experiment. Resolution was measured using stimuli at 25° eccentricity from the fovea (so as to be well clear of the blind spot) at each of the 8 principal meridians (0, 45, 90, 135, 180, 225, 270, and 315°) and also at 20° either side of 0 (nasal horizontal). Stimulus orientation was randomly selected to be either radial (parallel to meridian) or tangential (perpendicular to meridian), or either of the two oblique (half-way between radial and tangential) orientations. Five presentations were made at each orientation (i.e., 20 in each meridian) and results averaged for each meridian.

Resolution was measured using the strategy described by Thibos et al.[8] The subject fixated straight ahead while reducing the spatial frequency of the grating from an initially high value where no spatial contrast was visible. Further adjustment produced an often highly visible aliased pattern and, when reduced far enough, a sharp transition where the peripheral aliased percept disappeared and the veridical orientation of the gating could be reported with confidence. This point was taken as the resolution limit.

## RESULTS AND DISCUSSION

Using a sampling-limited psychophysical task, we have found that resolution acuity at fixed eccentricities is greater near the horizontal meridian than nearby and greater on the nasal retina than temporal. The data are presented in Fig. 1 as an average across orientation for both subjects and superimposed on an artist's impression of the human retina. The data indicate a significantly higher resolution limit for the horizontal nasal retina (6 cpd, SD 0.9 cpd) than for the next highest meridians, which were 20° either side (4 cpd, SD 0.6 cpd). Furthermore, acuity in the nasal retina was much better

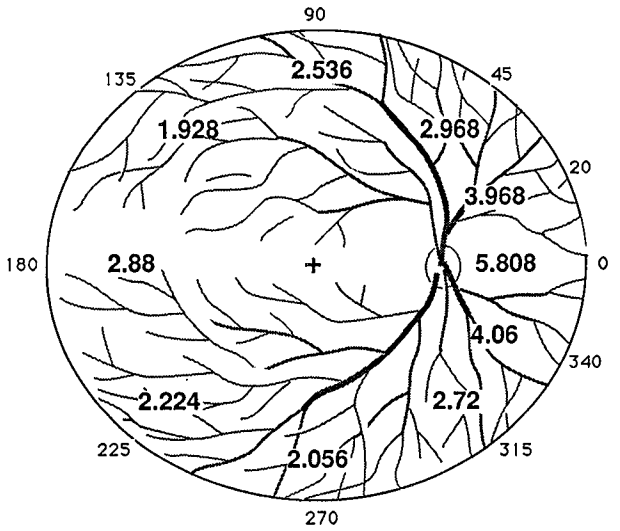


**Figure 1.** Resolution limit (cpd) at 25° for different retinal meridians.

than in the horizontal temporal retina (2.88 cpd, SD 0.6 cpd).

Plotting the average resolution acuities across meridians for the different grating orientations, we see that resolution was significantly higher for the radially oriented gratings than any other orientation (Fig. 2). Radial grating acuities were in fact highest at every meridian. These results agree with Rovamo et al.[15] in that radial orientations produced higher resolution acuities, but we did not find any real difference between the other orientations like those found by Rovamo et al. We attribute this to the removal of the effects of peripheral refractive errors and transverse chromatic aberration.

These results are consistent with the existence and localization of the human visual streak as described by Curcio and Allen.[13] To put the comparison on a more quantitative footing, we calculated the expected resolution limit by converting the data of Curcio and Allen from GC/mm$^2$ to the expected minimum angle of resolution in cycles per degree at 25° eccentricity (MAR=spacing=$\sqrt{\text{density}}$). The result is a predicted resolution of 7.1 cpd for the nasal retina, 4.28 cpd for the temporal retina, 4.79 cpd for the superior and 3.55 cpd for the inferior retina at 25° eccentricity if we assume that all ganglion cell types contribute. However, Thibos et al.[7] argued that visual resolution is probably limited by the spacing of beta ganglion cells, which are believed to account for approximately 80% of ganglion cells in the human retina.[21] Multiplying the above values by the square root of 0.8 modifies the above values to 6.4 cpd nasally, 3.85 cpd temporally, 4.31 cpd superiorly, and 3.2 cpd inferiorly, which is just higher than the average values measured psychophysically (see Fig. 3). Closer agreement between psychophysical acuity and anatomical predictions may not be possible because of individual differences. It was pointed out by Curcio and Allen that variation in both absolute number of retinal ganglion cells (0.7 to 1.5 million) and the ratio of superior to inferior ganglion cell density varied greatly between individuals, which would account for any differences in both vertical position and shape of the curves.

Error bars in Fig. 2 show ±1.0 SD and are equal to about 10% of the minimum angle of resolution. Variability in measurement is probably due to several factors. First, any small shift in fixation by the subject also means a shift in retinal location with each measurement and therefore the standard deviation may actually reflect small localized variations in ganglion cell density. Second, there will be some slight variability in the subject's estimation of the resolution limit due to the behavior of the aliased percept and shifting of criterion, although experience has shown this to be a remarkably distinct threshold.

## CONCLUSIONS

The visual streak described by Curcio and Allen[13] can be localized psychophysically by measurements of resolution acuity in the periphery which, when the effects of optical defocus are minimized, are limited by ganglion cell density. The fact that sig-

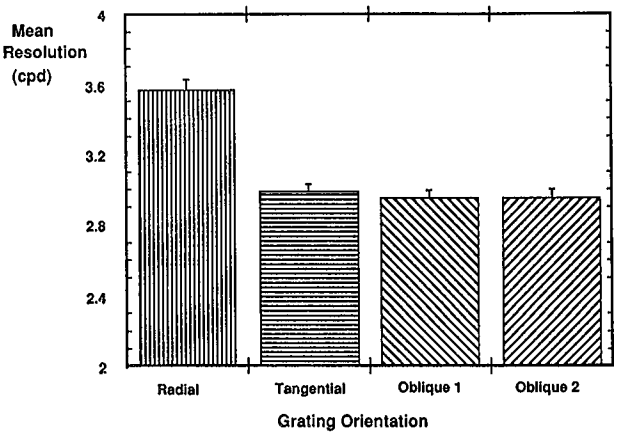


**Figure 2.** Plot of average resolution acuity across meridians (cpd) for different grating orientations.

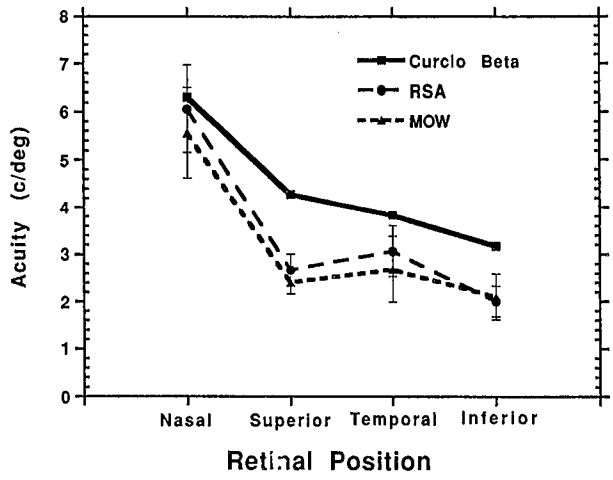


**Figure 3.** Comparison of psychophysical acuity with anatomical predictions.

nificantly smaller changes in ganglion cell density than those conventionally detected by perimetry can be measured easily demonstrates the fairly good sensitivity of this technique. Further research in this area may lead to clinical tests to detect disease and conditions of the visual system which, as part of their course cause death or dysfunction of ganglion cells and hence a change in their density.

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**REFERENCES**

1. Quigley HA. Early detection of glaucomatous damage. Part II. Changes in the appearance of the optic disk. Surv Ophthalmol 1985;30:117–26.
2. Bradley A, Thibos LN, Still D. Visual acuity measured with clinical Maxwellian-view systems: effects of beam entry location. Optom Vis Sci 1990;67:811–7.
3. Thibos LN. Optical limitations of the Maxwellian view interferometer. Appl Opt 1990;29:1411–9.
4. Curcio CA, Sloan KR, Kalina RE, Hendrickson AE. Human photoreceptor topography. J Comp Neurol 1990;292:497–523.
5. Ten Doesschate J. Visual acuity and distribution of percipient elements on the retina. Ophthalmologica 1946;112:1–18.
6. Weymouth FW. Visual sensory units and the minimal angle of resolution. Am J Ophthalmol 1958;46:102–13.
7. Thibos LN, Cheney FE, Walsh DJ. Retinal limits to the detection and resolution of gratings. J Opt Soc Am 1987;4:1524–9.
8. Thibos LN, Walsh DJ, Cheney FE. Vision beyond the resolution limit; aliasing in the periphery. Vision Res 1987;27:2193–7.
9. Williams DR. Visibility of interference fringes near the resolution limit. J Opt Soc Am 1985;A2:1087–93.
10. Anderson SJ, Hess RF. Post-receptoral undersampling in normal human peripheral vision. Vision Res 1990;30:1507–15.
11. Hughes A. The topography of vision in mammals of contrasting lifestyle: comparitive optics and retinal organisation. In: Handbook of Sensory Physiology, vol VII/5. The Visual System in Vertebrates. New York: Springer-Verlag, 1977.
12. Stone J, Johnston E. The topography of primate retina: a study of the human, bushbaby and new and old-world monkeys. J Comp Neurol 1981;196:205–24.
13. Curcio CA, Allen KA, Topography of ganglion cells in human retina. J Comp Neurol 1990;300:5–25.
14. Wertheim T. Peripheral visual acuity (1891). Translated by Dunsky, Am J Optom Physiol Opt 1980;57:915–23.
15. Rovamo J, Virsu V, Laurinen P, Hyvärinen L. Resolution of gratings oriented along and across meridians in peripheral vision. Invest Ophthalmol Vis Sci 1982;23:666–70.
16. Walsh DJ. Peripheral visual acuity; oblique and meridional effects. 1985. MS Thesis. Indiana University.
17. Lotmar W. Apparatus for the measurement of retinal visual acuity by moiré fringes. Invest Ophthalmol Vis Sci 1980;19:393–400.
18. Le Grand Y. Sur la mesure de l'acuite visuelle au moyen de franges d'interference. C R Seances Acad Sci Roum 1935;200:490–1.
19. Westheimer G. Modulation thresholds for sinusoidal distribution on the retina. J Physiol (Lond) 1960;152:67–74.
20. Thibos LN. Calculation of the influence of lateral chromatic aberration on image quality across the visual field. J Opt Soc Am 1987;A4:1673–80.
21. Perry VH, Oehler R, Cowey A. Retinal ganglion cells that project to the dorsal lateral geniculate nucleus in the macaque monkey. Neuroscience 1984;12:1101–23.

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